Paleobotanical Record of Eocene–Oligocene Climate and Vegetational Change Near Eugene, Oregon

Jeffery A. Myers, Department of Earth and Space Sciences, Western Oregon University, Monmouth, Oregon 97361; myersj@wou.edu

Paul R. Kester, Department of Earth and Space Sciences, University of Washington, Seattle, Washington 98195; pkester@u.washington.edu

Gregory J. Retallack, Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403; gregr@darkwing.uoregon.edu

OVERVIEW

At least five paleofloras bracket the Eocene–Oligocene boundary near Eugene in the southern Willamette Valley of western Oregon. Most of the floras occur within 2 km from marine rocks bearing late Eocene (Galvinian) molluscan and decapod faunas (Rathbun, 1926; Steere, 1955; Hickman, 1969). Two of the floras, the latest Eocene Goshen Flora (Chaney and Sanborn, 1933) and the early Oligocene Willamette Flora (undescribed), have long been regarded as critical indicators of vegetational and climatic change across the Eocene–Oligocene transition (Wolfe, 1981, 1994). Until recently, very little work has focused on the stratigraphic or geochronologic relationships of the strata that bear plant fossils within the sequence. Recent work by G.J. Retallack and D.R. Prothero has established magnetostratigraphic and physical stratigraphic relationships among the paleofloras. P.R. Kester and J.A. Myers are currently evaluating the detailed depositional framework and taxonomic relationships of the Willamette Flora. These studies provide important constraints on the timing and magnitude of climatic and vegetational events during the latest Eocene and early Oligocene.

This field trip will overview the stratigraphic, chronologic, and facies relationships between the Goshen, Willamette, and recently discovered Coburg Floras, and interfingering rocks of the Eocene-Oligocene marine Eugene Formation.

Field Guide to Geologic Processes in Cascadia: Oregon Department of Geology and Mineral Industries Special Paper 36, 2002.

FIELD TRIP ROAD LOG

0.0. Set trip odometer to zero at the Oregon 34 bridge over the Willamette River in Corvallis.

Here, the Willamette River incises Holocene alluvium of the "Willamette" and "Rowland" Formations (Yeats and others, 1996), the former representing deposits of the great Missoula Flood events. Between 30 and 50 flood events carried sediment and rafted ice southward up the Willamette Valley to the vicinity of Eugene, leaving behind silt and lithologically exotic dropstones.

The Willamette Valley is fundamentally a broad, faulted syncline bordered on the west by the Coast Range Anticlinorium, and on the east by the uplifted, westward tilting Western Cascades. The Corvallis Fault and many smaller displacement faults cut Holocene sediment in the valley (Yeats and others, 1996). In the middle to southern part of the valley, the majority of faults, along with broad subsidiary folds, strike generally northeast.

Near Corvallis, approximately 100 meters of Pleistocene and Holocene sediment cover broadly folded middle Eocene to early Oligocene marine strata of the Eugene, Spencer, Yamhill, and Tyee Formations, which rest unconformably upon the ocean floor basalt of the Siletz River Volcanics (Fig. 1). The sequence reflects the accretion of ocean floor basalt to Oregon's western margin, and subsequent infilling of a forearc trough, beginning with deep marine turbiditic sandstone of the Tyee Formation during the early to middle Eocene, and terminating with shallow shelf deposits of the Eugene Formation during the late Eocene to early Oligocene. Volcanic rocks within the

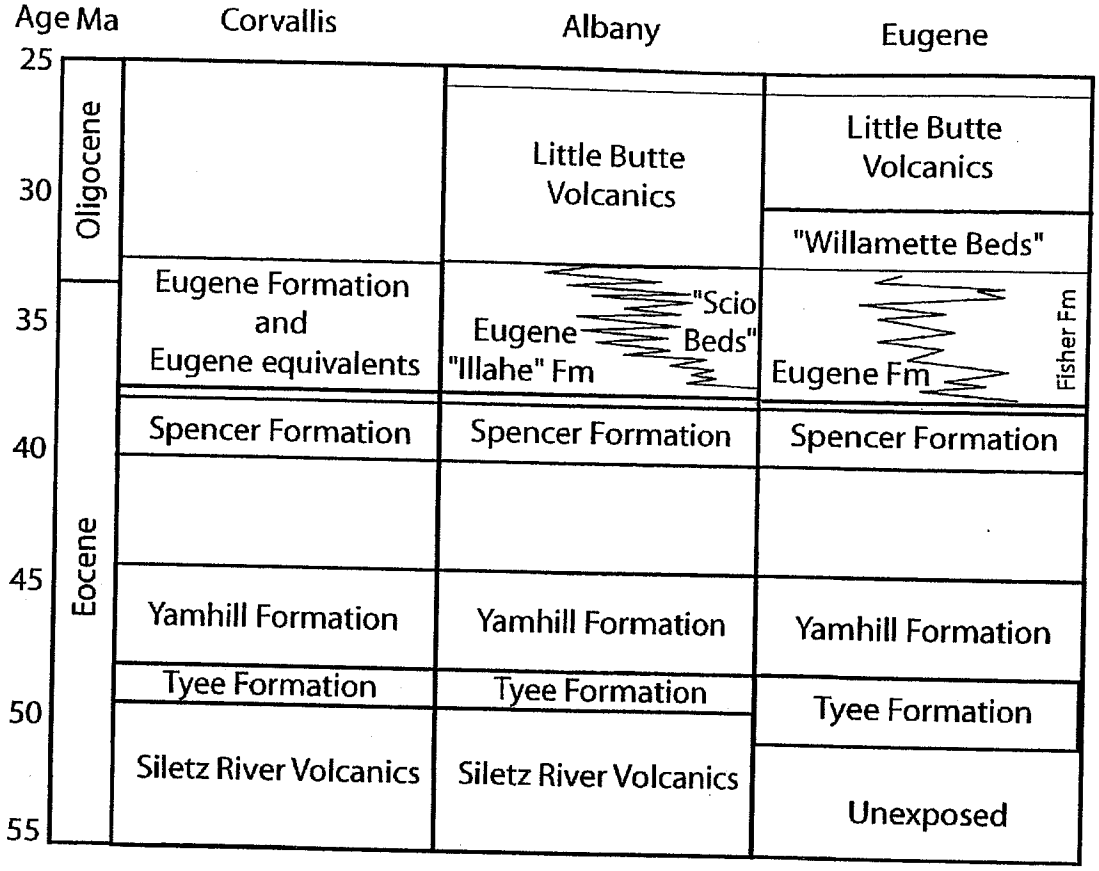

Figure 1. Stratigraphic relationships of Eocene and Oligocene rocks in the Willamette Valley (in part from Yeats and others, 1996).

Yamhill and younger formations record arc volcanism in the Western Cascades Arc, which commenced approximately 42 million years ago. By the middle Oligocene, agglomerate, breccia, and sandstone of the Western Cascades had infilled the forearc basin, and these rocks of the nonmarine Little Butte Volcanics lie conformably over older marine rocks. Uplift of the present Coast Ranges and deformation of the Willamette Valley along currently active structural features began during the latest Miocene.

Approximately 1.5 miles east of the Willamette River, we will cross the steeply-dipping Owl Creek Fault. This fault has produced approximately 120 meters of west-down offset in Pleistocene alluvium, but it apparently does not cut the Willamette Formation.

10.1 Enter I-5 Southbound

Many of the buttes to the east of I-5 are composed of flows and hypabyssal plugs of Oligocene–Miocene basalt of the Little Butte Volcanics of Peck and others (1964).

In the subsurface of this part of the valley, the Eocene–Oligocene Eugene Formation grades eastward into pumice-bearing, tuffaceous, nonmarine sandstone, which has been assigned variously to the "Mehama Volcanics", the "Scio Beds", and more recently (Peck and others, 1964) to the Little Butte Volcanics. The rocks are lithologically similar to and approximately coeval with the tuffaceous nonmarine Fisher Formation in the Eugene area, within which some authors (Yeats and others, 1996) have included them.

Eocene and Oligocene paleofloras are abundant in the midvalley east of Salem and Albany. These include the Sweet Home (Brown, 1950), Scio (Sanborn, 1949), Bilyeu (Klucking, 1964), and Thomas Creek (Eubanks, 1962; Klucking, 1964) Floras. The diverse Bilyeu Creek Flora compositionally resembles the latest Eocene Goshen Flora and is dominated by large-leaved tropical and near-tropical taxa. However, the Scio and Thomas Creek Floras include taxa common in Oligocene assemblages

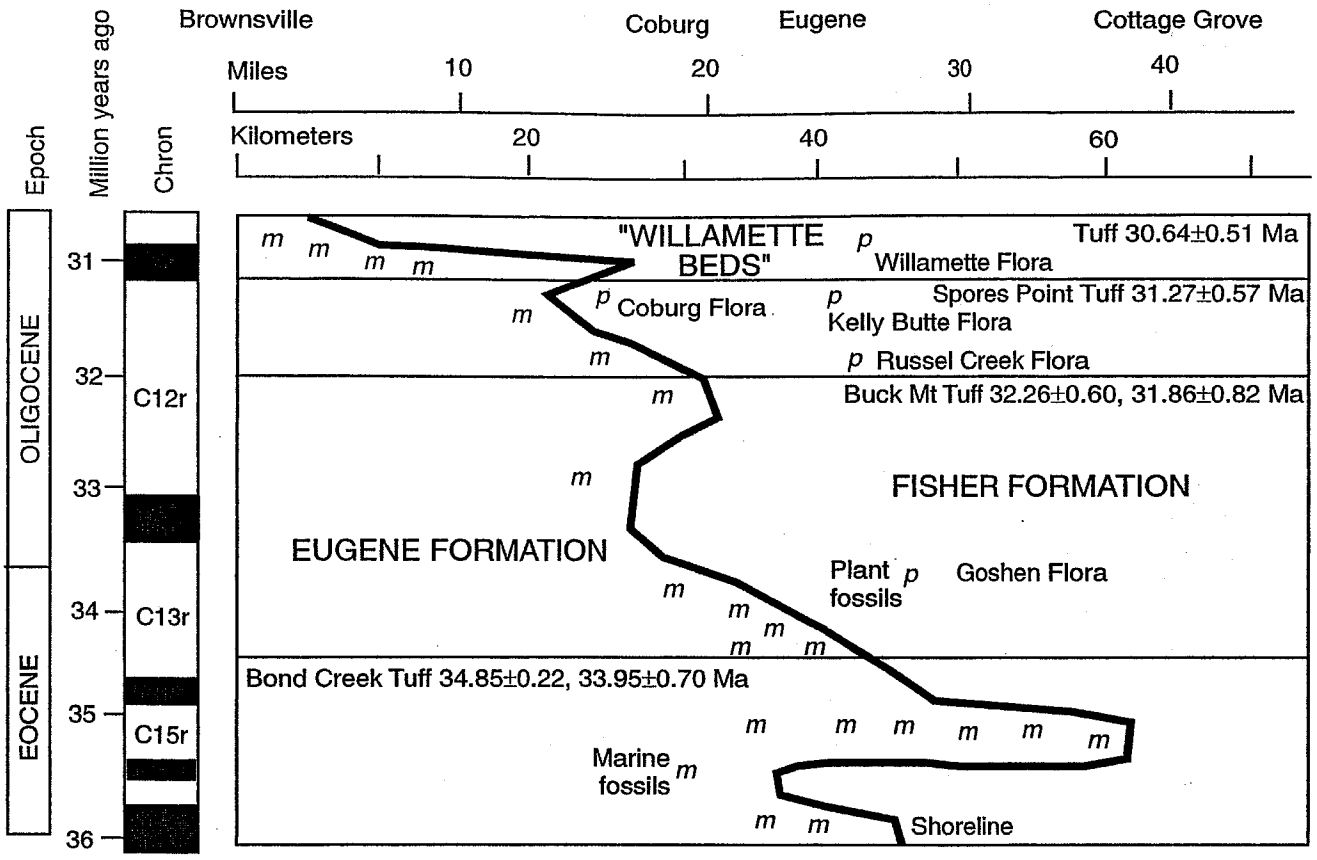

Figure 2. Correlation of rocks and fossil localities in the Eugene area. Magnetostratigraphy is from D.R. Prothero and G.J. Retallack (in prep). Localities for new $^{40}Ar/^{39}Ar$ dates are in Table 2.

from elsewhere in Oregon (such as *Acer, Alnus, Metasequoia, Pterocarya, Exbucklandia,* and others) that are not currently known from other low-elevation "Goshen-type" paleofloras in the Willamette Valley.

38.2 Ahead and to the left are the Coburg Hills. As we travel south toward Eugene, the Willamette Valley Synclinorium narrows to approximately 40 km in width. The steep face ahead of us is the scarp of a west-dipping normal fault on the eastern margin of the Willamette Valley Synclinorium. The Coburg Hills are composed of Western Cascades volcanic and sedimentary rocks, and shallow intrusives of the Little Butte Volcanics.

41.3 Excellent exposures of Little Butte Volcanics basalt flows and tuff are exposed on the cliff to the east of the freeway.

41.6 McKenzie River crossing.

46.2 Willamette River crossing.

50.3 Exit I-5 at the Goshen Exit (188A). Turn RIGHT at the bottom of the offramp. Continue one short block and turn LEFT on old HWY 99. Continue 2 miles to the freeway overpass.

52.5 Goshen Flora locality

STOP 1—I-5 NORTH ONRAMP SOUTH OF GOSHEN

Park well off the onramp just before it rises to the I-5 overpass.

Impressions of leaves, wood fragments, and rare reproductive structures comprising the Goshen Flora were first noted in 1920 by E.L. Packard, then of the University of Oregon, during construction of U.S. Highway 99 (Pacific Highway). R.W. Chaney and E.I. Sanborn monographed the flora in 1933, and type collections are housed at the U.C. Museum of Paleontology, Berkeley. Numerous revisions of

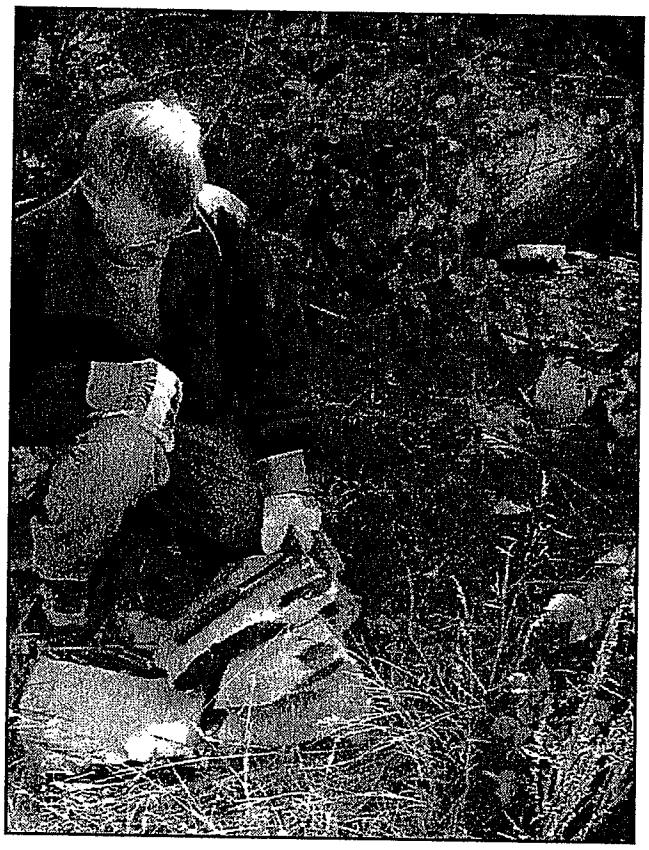

Figure 3. The Goshen Flora. Fossils are recovered from siltstone intervals. Pebble conglomerate is visible in the background.

individual taxa found in the Goshen Flora are scattered in the literature (Wolfe, 1977), but the flora would benefit from a thorough taxonomic review. Although the Goshen Flora has not been directly dated, recent $^{40}Ar/^{39}Ar$ dates from the Bond Creek Tuff, which underlies the Goshen Flora (Fig. 2), indicates that the flora must be younger than 34.85 ± 0.22 Ma (Kester, 2001). The flora is widely regarded to be latest Eocene in age, and was deposited prior to 33.7 Ma (Kester, 2001; Myers, in press).

The type locality of the Goshen Flora was covered during highway construction in the 1930s. However, several large blocks of tuffaceous sandstone and conglomerate from the original locality were brought to the surface during construction of a gas pipeline several years ago. A few parts of these blocks remain between the I-5 North onramp south of Goshen and the train tracks directly west of the onramp. Follow the cleared trail southwest from the onramp. The gray-brown blocks are scattered in the underbrush.

The Goshen Flora is contained in the late Eocene nonmarine Fisher Formation. Here, the Fisher Formation is composed predominately of yellowish-brown tuffaceous sandstone with pebble conglomerate stringers and finely-laminated carbonaceous intervals containing fossil plants (Fig. 3). Leaf impressions are found in pumiceous sandstone, which shows evidence of preburial weathering. Fossils are colored by a film of iron oxide which makes them stand out conspicuously against the light-colored matrix. The flora includes more than 50 taxa, including: Menispermaceae (*"Ficus" plinerva* Chaney and Sanborn), *Magnolia*, *Anona*, Lauraceae, Theaceae (*"Ilex" oregona* Chaney and Sanborn), *Allophyllus wilsoni* Chaney and Sanborn, *Meliosma aesculifolia* Chaney and Sanborn, *Meliosma goshenensis* Chaney and Sanborn, Anacardiaceae (*"Astronium" oregonum* Chaney and Sanborn), *Fagus oregona* (Chaney and Sanborn) Wolfe, Myrtaceae, *Cercidiphyllum*, *Plafkeria obliquifolia* (Chaney) Wolfe, *Florissantia speirii* (Lesquereux) Manchester, and *Platanus*. Some species found in the Goshen Flora are apparently limited in occurrence to the latest Eocene, including *Allophylus wilsoni* and *Meliosma aesculifolia*. These taxa are considered by Wolfe (1981) to be index species for a latest Eocene "Goshen-type" paleobotanical biozone.

Even without taxonomic revision, the Goshen Flora exhibits a strong floristic affinity to extant humid paratropical forests. This interpretation is supported by leaf physiognomic climate estimates, which yield a mean annual temperature (MAT) of about 19.5°C and annual precipitation in excess of 2300 mm/year, with no significant dry season.

On return to the vehicles, continue over the I-5 overpass. Turn LEFT on Peebles Rd, just to the east of the overpass.

54.6 Turn LEFT at Matthews Rd.

Very shortly after this you will turn LEFT at the intersection of Matthews Rd and Oregon 58. Warning: This is a very busy intersection.

Immediately move to the RIGHT lane and enter I-5 to Eugene.

55.5 Exit I-5 at the 188 B—(US 99 south) offramp

Continue to the base of the offramp and pull as far as possible onto the shoulder. Walk back up the offramp approximately 50 meters.

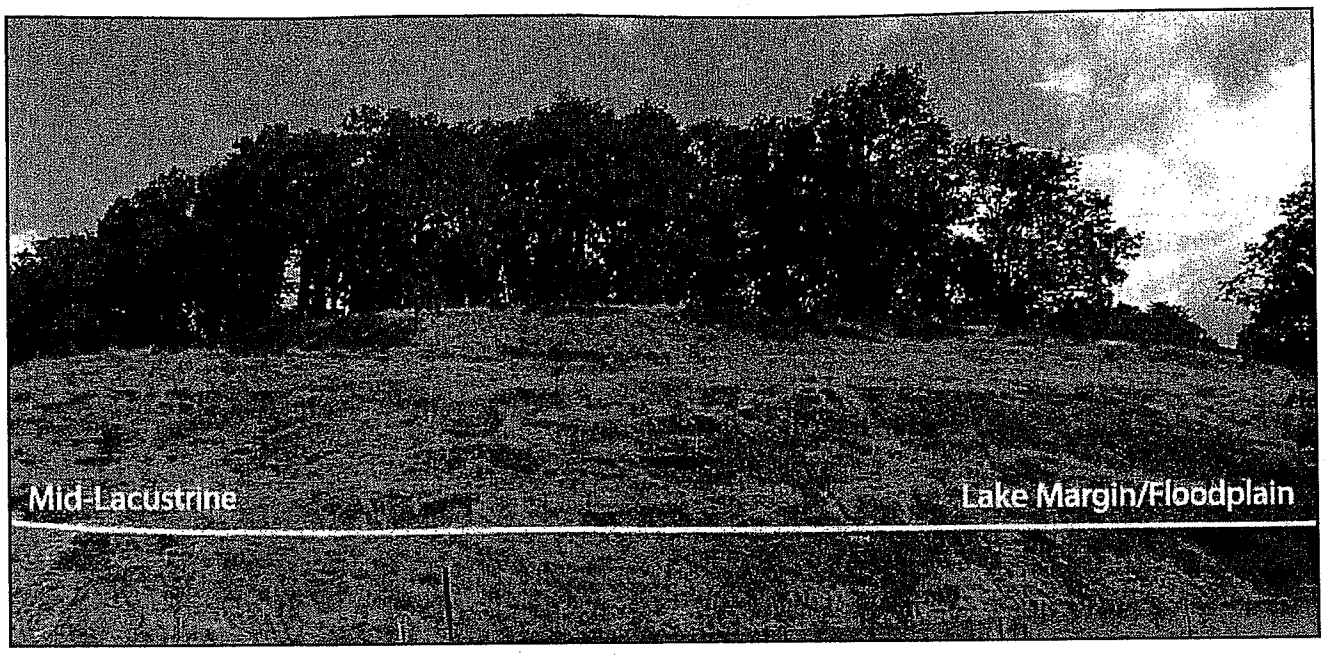

Figure 4. Overview of the freeway outcrop containing the Willamette flora. Fossil plants occur at two horizons. The primary fossiliferous interval is marked by the white line, and a second layer occurs near the top of the hill. The flora spans a range of depositional facies.

The Willamette Flora is exposed on the west-facing road cut above you (Fig. 4).

STOP 2. THE WILLAMETTE FLORA

The Willamette Flora has been mentioned in several brief taxonomic lists (Vokes and others, 1951; Brown, 1959; Meyer and Manchester, 1997), but it remains undescribed. The flora was originally collected from several localities. All of these but the freeway locality were destroyed during road construction. Large collections of the flora are housed at the U.C. Museum of Paleontology, Berkeley, the National Museum of Natural History, Washington, and the Condon Museum, University of Oregon.

The Willamette Flora occurs within a sequence of well-bedded, tuffaceous sandstone, mudstone, and pebble breccia, variously assigned to the lowermost interval of the Little Butte Volcanics (Wolfe, 1981) and to the Fisher Formation (Baldwin, 1981). The regularly bedded nature of the sequence, local occurrence of pumiceous tuff, and presence of carbon-rich horizons, closely resemble the Fisher Formation stratigraphically below it, whereas the presence of thick volcaniclastic debris flow deposits is characteristic of the Little Butte Volcanics. The contact between the Fisher Formation and the overlying Little Butte Volcanics likely is gradational. A $^{40}Ar/^{39}Ar$ date from near the top of the freeway exposure yielded an age of 30.64 ± 0.51 Ma (Kester, 2001).

The stratigraphic relationship between the Willamette Flora and the Goshen Flora, exposed not far to the south, is difficult to establish because of poor exposure and minor faulting. However, the distinctive well-bedded sequence containing the Willamette Flora can be followed north for several kilometers, where it includes fossilized upright tree stumps within debris flow deposits. The debris flow deposits comprise immature andesitic volcanics and suggest that the Willamette Flora grew in an unstable environment adjacent to increasingly active vents of the Western Cascades.

The flora is preserved in thinly and regularly bedded mudstone and coarse-grained sandstone. Excellent exposure at the freeway outcrop makes it possible to follow the fossiliferous bed for more than 100 meters along strike (Fig. 4). Fossils consist of black compressions in dark gray shale. Pervasive zeolitization makes the rocks difficult to cleave and quarry in slabs large enough to yield whole leaves, but with a little work excellent specimens can be recovered. At the south end of the outcrop, the

Figure 5. Soft-sediment deformation in thinly-laminated siltstone of the Willamette Flora fossiliferous interval. The overlying sequence is a volcaniclastic debris-flow deposit containing charcoalized wood.

fossiliferous interval is dominated by claystone, which we interpret to represent floodplain or lake-margin paleosols (Fig. 5). A lake-margin setting is compatible with the discovery of a fossil salamander *Palaeotaricha oligocenica* in these beds (van Frank, 1955). Near the north end of the outcrop, the fossil horizon consists of thinly-laminated mudstone. Plant fossils are superbly preserved, and the absence of fragmentation and evidence of preburial decay is suggestive of deposition in a midlake environment. Because the Willamette Flora spans lake-margin to midlake environments within a single outcrop, the flora provides an opportunity to examine facies-specific taphonomic and compositional biases.

We have recently examined all major collections of the Willamette Flora. At present we recognize approximately 60 taxa in the flora. A partial list is included in Table 1.

Many taxa seem to be holdovers from the warmer late Eocene (such as *Magnolia, Paleophytocrene*, Theaceae, *Meliosma, Fagus oregona*, and others). However taxa that are

Table 1. Preliminary List of Willamette Flora Taxa

Conifers
?Chamaecyparis sp.
Cunninghamia sp.
Fokeniopsis sp.
Gingko sp.
Keteleeria sp.
Metasequoia occidentalis (Newberry) Chaney
Pinus johndayensis Meyer and Manchester
Sequoia affinis Lesquereux
Tetraclinis sp.
?Torreya sp.
Angiosperms
Acer osmontii Knowlton
Alnus sp.
?Astronium sp.
Berhamniphyllum sp.
?Betula sp.
Cercidiphyllum/Joffrea sp.
Cinnamomophyllum sp.
Cercis maurerae Meyer and Manchester
Cedrela merrillii (Chaney) Brown
Crataegus merriamii (Knowlton) Meyer and Manchester
Cruciptera sp.
Exbucklandia oregonensis (Chaney) Brown
Fabaceae
Fagus oregona (Chaney and Sanborn) Wolfe
Florissantia sp.
?Hydrangia sp.
Juglandaceae
Lauraceae sp. (3 or more forms)
Magnolia sp.
Mahonia simplex
?Meliosma sp.
?Menispermaceae
Palaeophytocrene
Palaeocarya sp.
Plafkeria obliquifolia (Chaney) Wolfe
Platanus condonii (Newberry) Knowlton
Platanus exaspera Meyer and Manchester
Pterocarya sp.
Quercus consimilis Newberry
Quercus sp.
Rhus varians Lakhanpal
"Smilax"
?Theaceae
Ulmus sp.
?Zelkova sp.

Table 2. New $^{40}Ar/^{39}Ar$ Radiometric Dates for the Eugene Area, Oregon

Dated tuff	Location	Ma	Error ±
Dexter Tuff, NW of Jasper Railway Station	NW SE S10 T17S R2W	25.87	0.59
Tuff high above Willamette Flora near Goshen	SE SE S14 T17S R3W	30.64	0.51
Spores Point Tuff on river E of Spores Point	NW NW S10 T16S R3W	31.27	0.57
Buck Mountain Tuff at Short Mountain Landfill	NE NW S36 T17S R3W	31.86	0.82
Buck Mountain Tuff at Buck Mountain	SW NE S14 T15S R3W	32.26	0.6
Bond Creek Tuff in Willamette River	NW SE S32 T16S R3W	33.95	0.7
Bond Creek Tuff in Willamette River	NW SE S32 T16S R3W	34.85	0.22
Fox Hollow Tuff on Lorane Highway	SE NW S22 T17S R4W	40.98	0.56

Dates are from plagioclase by R.A. Duncan, Oregon State University.

taxonomically and numerically dominant in the flora are also found in the upland latest Eocene Cedarville Flora (Myers, 1998), the early Oligocene Bridge Creek Flora (Meyer and Manchester, 1997), and other Oligocene paleofloras from west of the Cascades (for example, the Rujada Flora, Lakhanpal, 1958). Shared taxa include *Sequoia affinis, Pinus johndayensis, Platanus condonii, Platanus exaspera, Quercus consimilis, Plafkeria obliquifolia, Rhus varians, Cedrela merrillii, Berhamniphyllum sp., Crataegus merriamii,* Ulmaceae, and many others. One of the most unique aspects of the flora is the diversity of conifers in the assemblage.

The Willamette Flora reflects a mesic warm temperate mixed broadleaved and coniferous vegetational source. Leaf physiognomic estimates from the flora yield a mean annual temperature of 13.5°C and approximately 1500 mm of seasonal rainfall. Cold-month temperature did not approach freezing, whereas warm-month temperature remained moderate (less than 20°C). These climatic conditions are ideal for many conifer lineages, and they probably account for the large diversity of conifers in the Willamette Flora.

The Willamette Flora is both floristically and vegetationally very different from the 1 to 2 million year older Goshen Flora. The stark contrast between the two floras is one of the classic and most often cited examples of profound vegetational change in response to Eocene–Oligocene climatic cooling. However, our examination of large collections from the Willamette Flora indicate a less than 6°C decline in mean annual temperature between the Goshen Flora and the Willamette Flora. Cooling was concomitant with a significant decline in precipitation, particularly during the dry season. Although climatic change alone does not seem to account for the dramatic vegetational and floristic transition between the two floras, "threshold" cold month temperature or dry season precipitation changes, perhaps combined with increasing impacts of environmental disturbance between the late Eocene and early Oligocene, may account for the dramatic shift in the composition, diversity, and relative abundance of the taxa growing near the depositional centers.

Return to the vehicles and continue north on old Highway 99 toward Eugene.

57.3 Texaco Station—If anyone needs a rest stop, this is a good place.

Continue north on old Highway 99 to the I-5 North freeway onramp. Continue toward Eugene.

59.1 Exit Glenwood–Springfield. Continue to Franklin Blvd, and turn RIGHT. Continue to Pioneer Parkway, Springfield.

60.8 Pioneer Parkway, Springfield. From old downtown Springfield Main Street head south on Pioneer Parkway across the railway tracks and then uphill for 1/2 mile to a long and high new road cut into the hill of Willamette Heights overlooking the Willamette River (NE NE NW NW section 2 T18S R3W Lane County).

61.4 STOP 3. PIONEER PARKWAY SOUTH

These near-horizontal volcanic-lithic and glauconitic sandstone beds are the upper part of the Eugene Formation. This facies is nearshore-marine and beach, and it is near the point where marine sediment grades upward

into a nonmarine facies. A large permineralized log lies near the middle of the exposed section, and molds and casts of marine surf clams *Spisula eugenensis* can be seen low in the section down the hill toward Springfield. In places the shells form coquina beds. The classic fossil sites of the Eugene Formation along the railway in Glenwood, across the Willamette River to the west, can be seen from here. Although widely regarded as Oligocene, only faunas of the Eugene Formation here, in the Coburg Hills, near Brownsville, and in Salem now seem to be Oligocene. Down section to the west of Springfield these marine rocks are late Eocene.

The Eugene Formation interfingers with rocks of the Fisher Formation (Vokes and Snavely, 1948). Molluscan faunas within the Eugene Formation are tied to the Lincoln and Keasey West Coast local biozones, and are broadly tied to the Galvinian Stage (Armentrout, 1981), *Molopophorus gabbi* and *M. stephenson* zones (Durham, 1944), and the *Acila shumardi* zone of Schenck (1936). Recent magnetostratigraphic work by Prothero and Hankins (2001) places the Keasey Formation within Chrons C15n to C12r, approximately 35 to 32.8 Ma, or latest Eocene to early Oligocene in the Berggren and others (1995) chronology. This assignment agrees with radiometric dates from the Bond Creek Tuff (McBirney, 1978; Murray, 1994; Kester, 2001), which occurs within the Eugene Formation near Eugene to the west of us.

Return to the vehicles, make a U-turn at Dorris Rd, and return NORTH on Pioneer Parkway through Springfield to Oregon 126 to Eugene. Continue WEST on Oregon 126 and return to I-5 North.

65.9 Exit 195 Beltline Florence–Airport. Continue west to Coburg Rd. Turn right (north) on Coburg Rd.

69.8 You will cross the McKenzie River. Just north of the river, turn RIGHT on McKenzie View. Continue slowly up McKenzie View for a little less than 1 mile.

70.7 Pull left and park at the fenced road. *Be sure to lock the vehicles here.*

STOP 4. THE COBURG FLORA

Walk up McKenzie View approximately 200 m. On your left above the landslide barriers is an outcrop of the Eugene Formation, which overlies the Fisher Formation at this place. These Oligocene marine rocks are illustrated in Figure 2.

Climb down the steep slope to the McKenzie River. Ropes are provided, but the path can be very slippery.

At the river, continue north along the bank for approximately 50 meters. The Coburg Flora is exposed along the river bank here.

The Coburg Flora occurs within tan muddy fine-grained sandstone of the Fisher Formation. Fossils are preserved as dark compressions. Although the flora has not been extensively collected to date, extremely well-preserved leaves, fruits, and wood have been recovered. The Coburg Flora is undescribed, and the only mention of a "Coburg Flora" comes from a letter from C.W. Washburne to W.D. Smith (1917) referring to "a collection of

Figure 6. Stump in growth position within the Spores Point Tuff at the Coburg Flora locality.

Oligocene leaves made on the Vanduzen place, east of Coburg" (cited in an unpublished catalogue of fossils by Hergert, 1954). A small collection from this locality was made by Leroy Detling of the University of Oregon.

The Coburg Flora is an autochthonous untransported assemblage. Wood and other plant debris is mixed within a paleosol, and growth-position tree stumps are common (Fig. 6). The fossiliferous horizon of the Coburg Flora is conformably overlain by the Spores Point Tuff. The tuff seems to have been deposited rapidly upon the forest floor, entombing the community nearly intact. A $^{40}Ar/^{39}Ar$ date from the Spores Point Tuff yielded an age of 31.27 ± 0.57 Ma (Kester, 2001). The age of the tuff is particularly important, because the tuff is coeval with the Coburg Flora, and hence provides the only direct date for an early Oligocene flora west of the Cascades.

Preliminary collections from the Coburg Flora include plants tentatively recognized as Celastraceae, Theaceae, Lauraceae, Urticaceae?, and others. These plants are indicative of a warm, moist climate, and more closely resemble the Goshen Flora than the Willamette Flora, although the apparent difference may be a product of taphonomic or growth-habitat biases.

Return to vehicles and make a U-turn to return to Coburg Road.

Turn RIGHT on Coburg Road.

73.5 Downtown Coburg. Turn RIGHT on Pearl St.

74.2 Enter I-5 North.

103.6 Oregon 34 (Exit 228) to Corvallis

114.2 Approaching the Oregon 34 bridge over the Willamette River, look up to see the huge osprey nest at the top of the eastern central bridge support.

REFERENCES

Armentrout, J.M., 1981, Correlation and ages of Cenozoic chronostratigraphic units in Oregon and Washington, *in* Armentrout, J.M., ed., Pacific Northwest Cenozoic Biostratigraphy: Geological Society of America Special Paper 184, p. 137-147.

Baldwin, E.M., 1981, Geology of Oregon: Dubuque, Kendall/Hunt, 170 p.

Berggren, W.A., Kent, D.V., Swisher, C.C., and Aubry, M.P., 1995, A revised Cenozoic geochronology and chronostratigraphy, *in* Berggren, W.A., Kent, D.V., Aubry, M.P., and Hardenbol, J., eds., Geocronology, time scales, and global stratigraphic correlation: Society of Economic Paleontologists and Mineralogists Special Publication 54, p. 129-212.

Brown, R.W., 1950, An Oligocene evergreen cherry from Oregon: Washington Academy of Sciences Journal, v. 40, p. 321-324.

Brown, R.W., 1959, A bat and some plants from the Oligocene of Oregon: Journal of Paleontology, v. 33, p. 120-124.

Chaney, R. W., and Sanborn, E. I., 1933, The Goshen Flora of central Oregon: Carnegie Institution of Washington Publication 439, 237 p.

Dalrymple, G.B., 1979, Critical tables for conversion of K-Ar ages from old to new constants: Geology, v. 7, p. 558-560.

Durham, J.W., 1944, Megafaunal zones of the Oligocene of northwestern Washington: University of California Department of Geological Sciences Bulletin, v. 27, p. 101-211.

Evernden, J.F., and James, G.T., 1964, Potassium-argon dates of the Tertiary floras of North America: American Journal of Science, v. 262, p. 945-974.

Eubanks, W., 1962, The fossil flora of Thomas Creek: Ore Bin, v. 24, p. 26-27.

Hergert, H.L., 1954, Tertiary floras of Western Oregon and their geological significance: Oregon State University MS Thesis, 87 p.

Hickman, C.J.S., 1969, The Oligocene marine molluscan fauna of the Eugene Formation in Oregon: University of Oregon Museum of Natural History Bulletin, v. 16, 112 p.

Kester, P.R., 2001, Paleoclimatic interpretation from the early Oligocene Willamette Flora, Eugene, Oregon: University of Washington MS Thesis, 62 p.

Klucking, E., 1964, An Oligocene flora from the Western Cascades: University of Caliifornia Berkeley PhD Dissertation, 241 p.

Lakhanpal, R.N., 1958, The Rujada Flora of west central Oregon: University of California Publications in Geological Sciences, v. 35, 66 p.

McBirney, A. R., 1978, Volcanic evolution of the Cascade Range: Annual Review of Earth and Planetary Sciences, v. 6, p. 437-456.

Meyer, H.W., 1973, The Lyons Flora of northwestern Oregon: Ore Bin, v. 35, p. 37-51.

Meyer, H.W., and Manchester, S.R., 1997, Revision of the Oligocene Bridge Creek Floras of Oregon: University of California Publications in Geological Sciences, v. 141, 191 p.

Murray, R.B., 1994, Geology and mineral resources of the Richter Mountain 7.5 Minute Quadrangle, Douglas and Jackson Counties, Oregon: University of Oregon MS Thesis, 250 p.

Myers, J.A., 1998, Paleovegetational heterogeneity and the record of Eocene–Oligocene climate change in the interior Pacific Northwest: University of California Santa Barbara PhD Dissertation, 502 p.

Myers J.A., in press, Terrestrial Eocene–Oligocene vegetation and climate in the Pacific Northwest, *in* Prothero, D.R. ed., The marine Eocene–Oligocene transition: Cambridge University Press.

Peck, D.L., Griggs, A.L., Schlicker, H.G., Wells, F.G., and Dole, H.M., 1964, Geology of the central and northern parts of the Western Cascade Range in Oregon: U.S. Geological Survey Professional Paper 449, 56 p.

Prothero, D.R., and Hankins K.G., 2001, Magnetic stratigraphy and tectonic rotation of the Eocene–Oligocene Keasey Formation, northwest Oregon: Journal of Geophysical Research v. 105, p. 16,473-16,480.

Rathbun, M.J., 1926, The fossil stalk-eyed crustacea of the Pacific Slope of North America: U.S. National Museum Bulletin, v. 138, 155 p.

Sanborn E.I., 1949, The Scio Flora of western Oregon. Oregon State College Studies in Geology, no. 4, 29 p.

Schenk, H.G., 1936, Nuculid bivalves of the genus *Acila*: Geological Society of America Special Paper 4, 149 p.

Steere, M.J., 1955, Fossil localities of the Eugene area, Oregon: Ore Bin, v. 20, p. 51-59.

van Frank, R., 1955, *Palaeotaricha oligocenica*, new genus and species; an Oligocene salamander from Oregon: Breviora, v. 45, p. 1-12.

Vokes, H.E., and Snavely, P.D., Jr., 1948, The age relationships of the Eugene and Fisher Formations: Geological Society of the Oregon Country Geological Newsletter, v. 14, p. 38-41.

Vokes, H.E., Snavely, P.D., Jr., and Myers, D.A., 1951, Geology of the southern and southwestern border areas of the Willamette Valley, Oregon: U.S. Geological Survey Oil and Gas Investigation Map OM110.

Wolfe, J.A., 1977, Paleogene floras from the Gulf of Alaska region: U.S. Geological Survey Professional Paper 997, 108 p.

Wolfe, J.A., 1981, A chronologic framework for Cenozoic megafossil floras of northwestern North America and its relation to marine geochronology, *in* Armentrout, J.M., ed., Pacific Northwest biostratigraphy: Geological Society of America Special Paper 184, p. 39-47.

Wolfe, J.A., 1994, Tertiary climatic changes at middle latitudes of western North America: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 108, p. 195-205.

Yeats, R.S., Graven, E.P., Werner, K.S., Goldfinger, C., and Popowski, T.A., 1996, Tectonics of the Willamette Valley, Oregon: U. S. Geological Survey Professional Paper 1560, p. 183-222.

Field Guide to Geologic Processes in Cascadia

Field Trips to Accompany the 98th Annual Meeting of the Cordilleran Section of the Geological Society of America May 13–15, 2002, Corvallis, Oregon

Edited by
George W. Moore
Oregon State University

2002

Oregon Department of Geology and Mineral Industries
Special Paper 36